

REAL SCIENCE, REAL EDUCATION: THE UNIVERSITY NANOSAT PROGRAM (POSTPRINT)

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Real Science, Real Education: The University Nanosat Program

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ABSTRACT

The University Nanosat Program (UNP) is a two year small satellite competition held among leading universities across the nation. In the past 12 years, UNP has involved 27 universities and over 5000 students in a variety of engineering fields and other disciplines, in the process of designing and managing the development of a satellite. The UNP is a partnership between the Air Force Office of Scientific Research (AFOSR), the Air Force Research Laboratory (AFRL), and the American Institute of Aeronautics and Astronautics (AIAA). The program's primary purpose is to help train engineering students in satellite design, fabrication, and testing by requiring them to build the satellite themselves through the mentorship of their Principle Investigator, industry mentors, and a series of six program reviews managed by the AFRL Program Office. Each university-built satellite attempts to further a specific technology or perform a scientific mission. Technologies advanced through the program include all aspects of small satellite designs including structures, propulsion, imaging, and navigation and have helped further science payloads such as energetic particle detectors, plasma probes, photometers, and many others. This paper will discuss the educational impact on students involved in a hands-on, hardware focused program. The paper will also address the recent launch of FASTRAC, the Nanosat-3 (NS-3) competition cycle winner built by the University of Texas at Austin, the upcoming launch of CUSAT, the NS-4 winner built by Cornell University; as well as the NS-5 winner DANDE built by the University of Colorado - Boulder. It will discuss the program's design philosophy as well as the challenges in creating space flight hardware with a small budget on a student schedule. Finally, the article will discuss some of the upcoming changes in the program such as the acceptance of CubeSats as equal competitors with the standard 50 kg nanosatellites.

INTRODUCTION

The University Nanosat Program (UNP) began in 1998 as a partnership between the Air Force Office Scientific Research (AFOSR), the Air Force Research Labs (AFRL), the American Institute of Aeronautics and Astronautics (AIAA), the Defense Advanced Research Programs Agency (DARPA), and the National Aeronautics and Space Administration (NASA). The program's original mission was twofold: address the dwindling number of aerospace engineers, and to investigate the ability to build inexpensive satellites. The structure of the first two competitions involved funding groups of universities with the intent of flying all of the satellites upon completion. However, due to

the challenges of building a satellite in an academic environment, the maturity of technologies in the small satellite world, and the limited resources of the Program Office resulted in only one of the satellites launching. At this point NASA and DARPA left the competition due to priorities in other areas. With NASA and DARPA leaving, and folding in lessons learned from the two previous rounds, the program was restructured to be a competition between approximately 11 schools with a down-select to one winner after a two year design and fabrication period. Each of the schools proposed their own mission, developed their requirements, and fabricated their own 50kg or less microsatellite during the two year period. Technical

oversight and mentoring was provided by AFRL. During the Nanosat (NS)-3 competition, the expectation was for each school to build a engineering level satellite. This resulted in hardware and software that required a substantial amount of work toward completion once the satellite was chosen as the winner. This led to a change in expectation in the NS-4 competition through NS-6 competition which required a flight version of the satellite to be built in the two year time frame. However, this requirement turned out to be beyond the capability for most university programs with a 50 kg satellite and paved the way toward the most current competition structure discussed later in this paper.

With continued development of the small satellite community, UNP has included CubeSats in the competition with the University of Hawaii's CubeSat placing third in our last cycle. The inclusion of CubeSats into the competition raises questions concerning evaluation of the utility of a more complete CubeSat versus a 50kg microsat that has more utility but may require additional effort to complete. The inclusion of CubeSats has also raised the question of ensuring the utility of the CubeSat even if it is educational. With a 50 kg spacecraft, the resources required to complete it has necessitated a level of commitment by the university providing for professors and programs to last over many years. However, with CubeSats one could feasibly fabricate one in a short time frame, but not ensure it is relevant, or there are people around to use the data once it is launched several years later. This issue is discussed in depth at the end of the paper. The importance of tying the educational process to real science missions and requirements is important and is the focus of this paper. In the following pages we discuss the program structure, some of the program results, and the direction the program is heading.

PROGRAM OVERVIEW

The University Nanosat Program is currently a partnership between AFOSR, AFRL, and AIAA. The partnership is arranged such that AFOSR provides funds for the development of the satellites at each school, AFRL supplies the program staff to organize and manage the competition including programmatic and technical oversight, and AIAA funds the Flight Competition Review where the program performs its downselect. In previous years, the AFRL staff was managed through the Space Vehicles Components branch, but has recently moved to the Space Vehicles Flights Programs branch (AFRL/RVEP). UNP has been integrated into the AFRL/RVEP small satellite portfolio which has provided for a better sharing of ideas, and lessons learned on small satellite development.

Structure of Program

The structure of the University Nanosat Program is built around a series of 10 scheduled milestones: a kick-off meeting, six design reviews, and three skill building events with a focus on education and team development. It is expected at each milestone that the students are the presenters with support from the Principle Investigator. The Kickoff meeting for the new competition cycle is held in conjunction with the Flight Competition Review (FCR) from the previous competition. This provides new schools the ability to see what is expected of them at the end of the two years. Closely following the Kickoff meeting is the System Concept Review (SCR). SCR is where the school expounds on the mission they proposed for the BAA and the first opportunity for the program office to provide feedback on the design. Following SCR the Program Office works with schools to find mentors within AFRL, other government agencies such as NASA and SMC, and industry partners to help focus the science or technical mission and shape the primary mission requirements. This process leads to the System Requirements Review (SRR) held at the end of the Spring Semester. SRR is focused exclusively on the requirements for the satellite and ensuring all the driving aspects of the mission are captured. In small satellite design the requirements process diverges from the traditional process of a large flight program. Due to the small volume, reduced budget, and short schedule, hardware availability drives the mission nearly at the level of the primary mission objectives. Oftentimes the mission objectives are selected based on the hardware that is available. Although one may argue from a pure systems perspective that this is backwards, it is the reality that most small satellite fabricators face, thus the requirements process should capture this challenging dynamic.

Following SRR, the next program milestone is the Student Hands On Training Workshop I (SHOT I) hosted by the University of Colorado – Boulder. SHOT I is a four day course in systems engineering where four members of each team fly to Boulder and participate in team building engineering challenges. The climax of the workshop is a high-altitude balloon launch where the students fly small payloads they've assembled at the workshop. The goal of the program is to build teamwork and demonstrate the challenges involved in assembling even a pre-designed payload and having it work reliably. A few months after SHOT I, the Preliminary Design Review (PDR) is held in conjunction with the Small Satellite Conference in Logan, Utah. Immediately following the conference, a panel of reviewers representing industry, academia, and government provide feedback on the designs of each of the schools. The next milestone is a Satellite

Fabrication Class held at AFRL's Aerospace Engineering Facility (AEF) on Kirtland Air Force Base in Albuquerque, NM. The two day class steps each of the teams through the fundamentals of satellite fabrication practice. This includes Electrostatic Discharge (ESD) prevention, good cleanroom practices, proper PCB soldering techniques, cable assembly, fastener torque, and a tour of environmental test equipment such as vibration tables, spin balance machines, thermal vacuum chambers, and others.



Figure 1 are images from the NS-5 Students Hands On Training (SHOT) workshop. SHOT is a team and skill building workshop for schools in the UNP competition.

In the spring of the second year of the competition the Program Office travels to each of the competing schools, along with members of AFRL and the Aerospace industry involved in relevant technologies, to take part in the Critical Design Review (CDR). This full day review is a dive into each of the spacecraft subsystems and the first truly detailed review for the programs. It is expected that members of each subsystem present to the review panel, with a tour of the facilities capping off the event. In the summer following CDR the second Student Hands On Training (SHOT II) workshop is held. At this workshop payloads from each school are integrated onto the high altitude balloon as a technology demonstration. Most schools chose to fly systems such as communication units for range testing. Following SHOT II the Proto-Qualification Review (PQR) is in conjunction with the beginning of the Small Satellite Conference. Once again members of the aerospace community provide critical feedback to each of the schools on their designs. The culmination of the competition is a day long, AIAA Flight Competition Review (FCR) held in Albuquerque, NM. FCR is the downselect from approximately 11 schools to at least one program moving forward to be presented for launch at the Space and Missile Center's Space Experiments Review Board. The scoring at FCR is a combination of the maturity of the satellite, the educational involvement (undergraduate, graduate, and k-12 outreach), participation at each review including

submission of required deliverables, and military relevance. Following those criteria a group of approximately 20 judges representing government agencies, academia, and industry select the winner of the competition. . At this point, the Program Office begins to work with the winning team, and the remaining schools are released from the competition. However, the schools that do not win the competition are encouraged to work with other industry and government organizations to procure launch opportunities of their own.

Table 1 illustrates programmatic milestones for NS-7

Programmatic Element	Approximate Date
Kickoff	January, 2011
System Concept Review	February, 2011
System Requirements Review	April, 2011
Student Hands On Training Workshop I	June, 2011
Preliminary Design Review	August, 2011
Satellite Fabrication Course	October, 2011
Critical Design Review	January/February, 2012
Students Hands On Training Workshop II	June, 2012
Proto-Qualification Review	August, 2012
Flight Competition Review	January, 2013

The competition incorporates a set of required deliverables at each review to help teach a robust design process. These deliverables include presentation slides, program overview documents, Requirements Verification Matrix, CAD designs, student participation, and may others. As an example Figure 2 illustrates the required deliverables for each teams mechanical design. At SCR, general structural requirements should be understood (i.e. CubeSat vs 50 kg spacecraft). By SRR a basic CAD model should be completed and rough volume allocation performed. At PDR a model fabricated from easily modifiable material such as foam, rapid prototyping, or wood

should be completed. This allows for students to get a feel for cable routing, and the real size of components that is difficult to grasp in a CAD model. Lessons learned should be fed back into the CAD so that by CDR a realistic model has been developed. Following CDR schools should begin cutting their engineering model hardware and performing their first spacecraft assembly. By FCR any lessons learned from the

engineering hardware should be fed back into the CAD for a final flight fabrication if selected. A similar design process with matching deliverables has been developed for both PCBs and software.

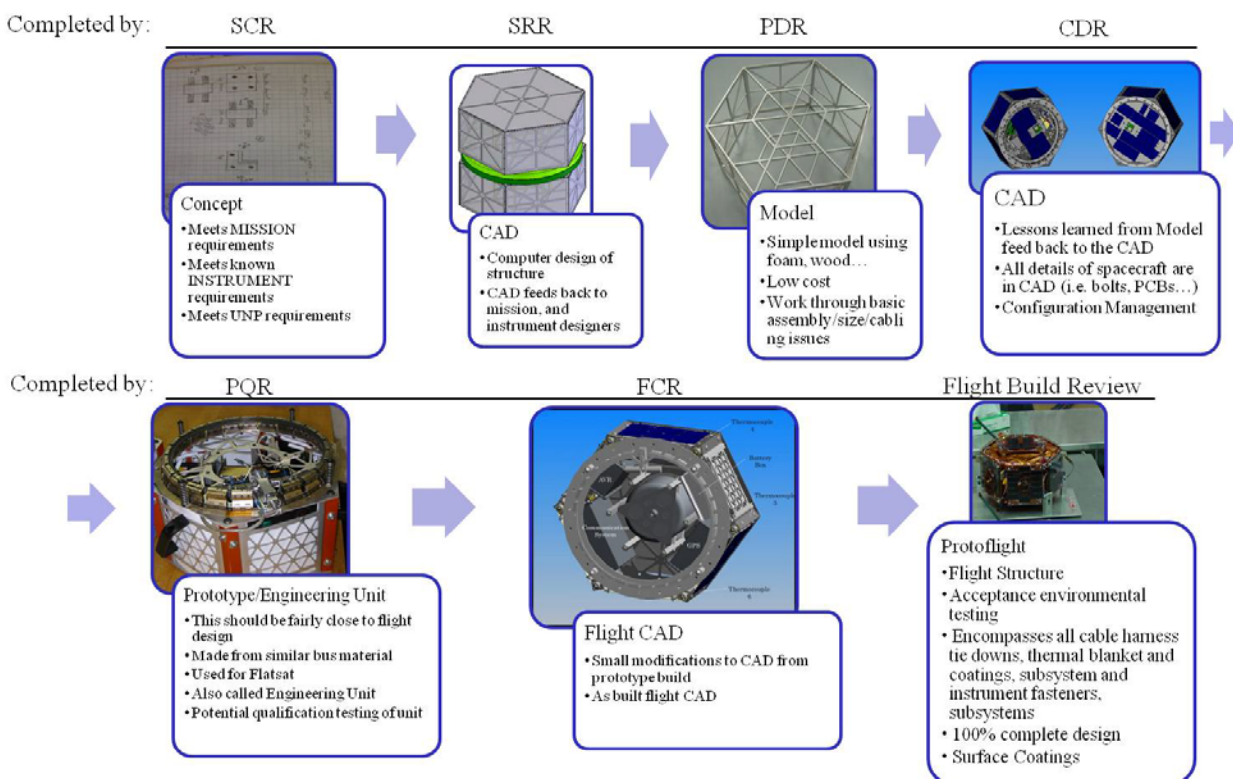


Figure 2 provides an example of design process UNP teams must step through in the fabrication process. Deliverables for each review are called for each of milestone.

Folding in lessons learned from previous competitions, UNP has implemented a set of reviews for the winner of the competition. Following FCR, a deep dive is scheduled at the winning. A set of progress reviews are planned approximately every three months following the deep dive and provides milestones for the student teams to work towards. Prior to integration of the flight hardware, an Integration Readiness Review (IRR) is held at the university. After the satellite is integrated and system testing is completed a Pre-Ship Review (PSR) is held. The satellite is then delivered to AFRL for environmental testing and performance testing before integration to the launch vehicle.

Goals of the Program

There are three goals to the University Nanosat Program that underpin all programmatic events. These three goals can be seen in Figure 3. The primary goal is educating the next generation of spacecraft engineers and is composed of two priorities: the advancement of systems engineering students, and students with experience in hardware integration, test and flight operations. The systems engineering students listed above are those who have worked on hardware and understand their subsystem is a component of a larger system. The goal of the program in this regard is to force students to learn the hard lessons of engineering by allowing them to do it themselves. The second priority is to have students who have participated in

flight operations, which is unfortunately limited to the winning program.

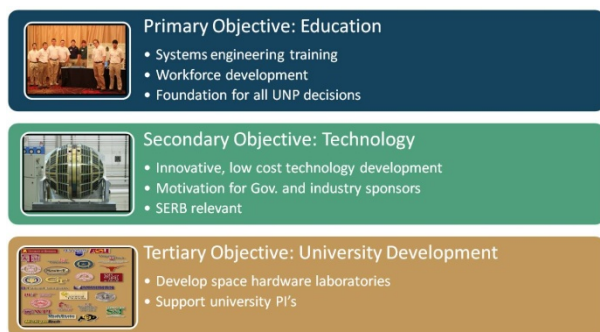


Figure 3 illustrates the three priorities of the University Nanosat Program. The Program Office is required to balance these sometimes competing priorities.

The two secondary objectives of the program have strong benefits to the aerospace community through the development of capable, small satellite technologies, and the development of satellite hardware laboratories at US universities. Some of the technologies that have been worked on through UNP will be discussed later in this paper.

Partnerships

The University Nanosat Program succeeds only through partnerships between students and professors, academia and government, professional organizations and government entities, and industry and academia. As was discussed earlier, the program itself is a partnership between two Air Force offices, and a professional organization. In the academic sphere, professors partner with dozens of students to design and build their program's satellite. This hands-on partnership provides opportunities to professors to share their knowledge and experience on engineering topics that are not typically addressed in most engineering programs, but are essential for good spacecraft engineering. Another partnership that enhances the educational experience is the involvement of government labs and industry as mentor or interested partners in a science or technology mission. This partnership provides students with the opportunity to collaborate with professionals, be exposed and understand requirements based designing, potential donation of hardware or funds, and possible job offers once they graduate from school. The government lab or industry partner benefits as well through the partnership through the opportunity to hire students with hands on hardware experience, a possible flight opportunity for their technology or science research area increasing their Technology Readiness Level (TRL), and the experience to help train the next

generation. Overall the benefits to all involved in the program are significant.

PROGRAM RESULTS

Any program must be evaluated against the objectives set forth and whether they have been met, not merely by what they intend to do. This is especially true in education where it is very easy to claim success merely by working with students, and not evaluating the output of the education. In this section we focus on four results of the University Nanosat Program

Impact on Students

The first result of the University Nanosat Program is the number of students who have been involved in the program over the last 10 years. Unfortunately, schools were not required to submit student participation until the NS-4 competition, and then it was only for the total number of students, not broken down by year or discipline. Even so, enough of the schools reported the participation to demonstrate the significant impact that the program is having on US students and universities. With three of the first six competitions reporting student participation, and only just having started the seventh competition, there have been 2,122 undergrads and 177 graduate students (Figure 4) who have participated in the University Nanosat Program as part of a spacecraft design team. We expect the actual involvement to be almost twice the reported value. These students represent a total of 27 US universities from 19 states.

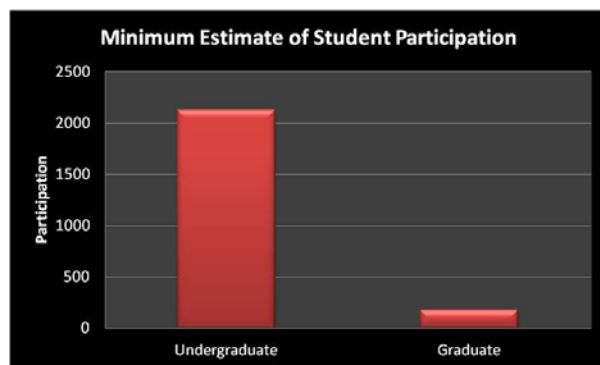


Figure 4 Number of documented students who participated in the seven UNP competitions. However, this number represents only approximately 50% of the students as Universities were not required to provide participation numbers in the early competitions.

Of these thousands of students the educational disciplines reflected in the design teams varies greatly with each universities program. Figure 5 illustrates the academic composition of two of our schools spacecraft

design teams. As the example shows one program is dominated by students from the Electrical and Computer Engineering discipline while the other program is dominated by students from the Aerospace Engineering Discipline. How the schools adapt based on the composition of their student teams is reflected in the final product produced by the school.

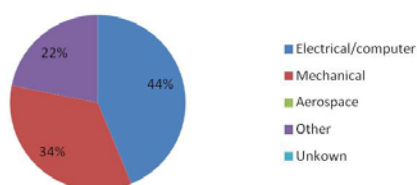
In addition to the collegiate student involvement the University Nanosat Program requires a K-12 educational outreach component to each program. Unfortunately, the tracking for the K-12 outreach has been significantly underreported. Based off of the reported numbers from the different schools they have reported outreach efforts involving 3,000 elementary students and approximately 500 high school students. However, this estimate appears to grossly underestimate the outreach programs as many programs merely stated that their outreach included “hundreds” of students. The K-12 outreach included anything from presentations to elementary students, through high school students building an auxiliary payload for some of the satellites.

journals and conference proceedings, as well as a few patent applications.

Technologies Developed

As mentioned earlier, one of the secondary goals of the program is technology development. Students often times come up with innovative methods of tackling problems because they are not familiar with how spacecraft design is traditionally done. One of the responsibilities of the Program Office is to identify these innovative approaches while redirecting the impractical ones. Each schools mission typically has a primary mission and a number of secondary objectives. The following figure illustrates the number of technologies that have been investigated through the seven competition cycles. Many of these technologies have not flown, but were advanced to an engineering unit level design and were precursors to other programs. One of the advantages to the University Nanosat Program is the risk the program is able to accept due to the educational mission of the programs.

Example 1 - Participation by Major



Example 2 - Participation by Major

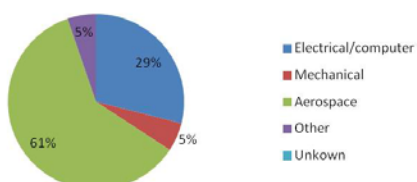


Figure 5 illustrates the varied participation of disciplines at two representative UNP schools.

There has been very limited tracking of alumni once they graduate from the University Nanosat Program although there is a current effort underway to attempt to track this extremely challenging metric. Even with the limited tracking the authors are aware of students at AFRL, NASA, Johns Hopkins, APL, Orbital, Lockheed, Sandia National Labs, Northrop Grumman, Los Alamos, SpaceX, and a host of other companies. We are also aware of dozens of papers published in

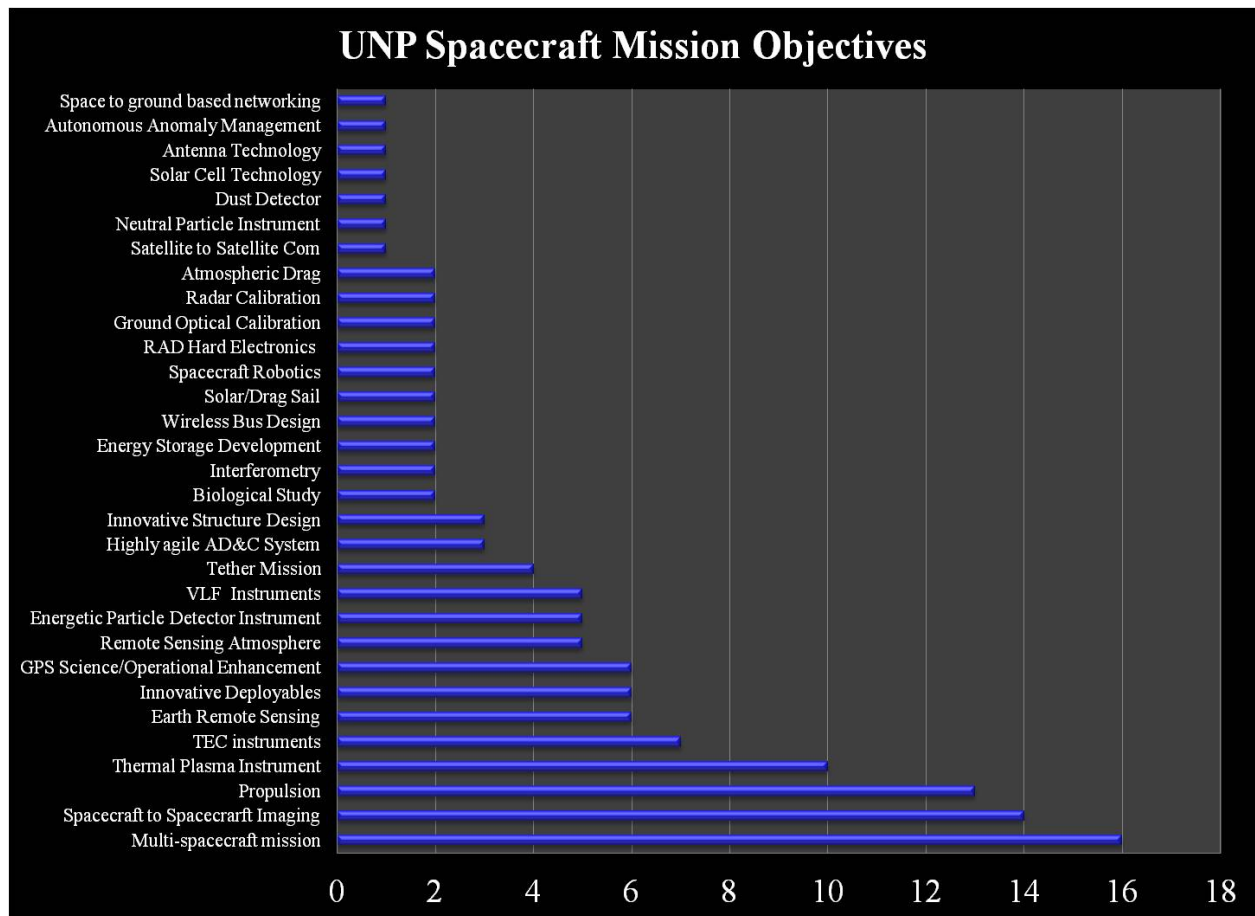


Figure 6 shows the various spacecraft technologies that have been investigated by UNP schools. Each university program tends to have at least one major objective and several secondary objectives.

In Figure 6 there tends to be a significant interest in multi-spacecraft missions followed by space weather missions. Both of these areas lend themselves well to small satellites and the capabilities of that particular size platform. The missions that are proposed reflect the technical capabilities of the PI and the universities background. This is an essential component to the program and allows for continuity of information as students come and go.

rapid deorbit of the satellite prior to mission start. However, there was a success beyond the educational benefit of the program. 3-CornerSat resulted in the first demonstration of Planetary Systems Corporation's (PSC) Mark I latching Lightband. The Lightband was developed through a Small business Innovative Research (SBIR) to PSC by the University Nanosat Program. The Lightband has now become the standard for releasing secondary payloads.

Program Successes

Three Corner Sat

There have been a number of technical successes to the University Nanosat Program. The first satellite to fly through the program was Three Corner Sat, shown in Figure 7, a partnership between New Mexico State University, the University of Arizona, and the University of Colorado - Boulder. 3-CornerSat's objective was to perform stereoscopic imaging of clouds and demonstrate formation flying. Unfortunately, the launch vehicle failed to make orbital insertion and 3-CornerSat was released into a low orbit resulting in a

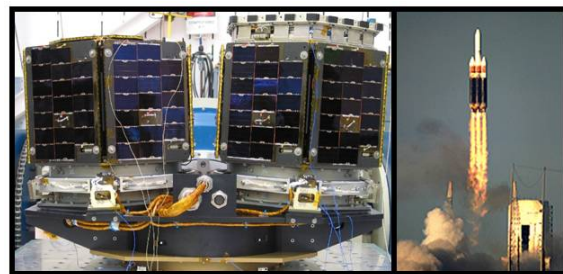


Figure 7: The figure on the left shows 3 CornerSat and the figure on the right is the launch of the Boeing Delta IV Heavy.

FASTRAC

The University of Texas at Austin developed the Formation Autonomous Satellite with Thrust, Rel-nav and Crosslink, or FASTRAC, which was the winner of the NS-3 competition. FASTRAC was launched in November, 2010 through the Space Test Program's (STP) STP-S26 mission. As can be seen in Figure 8, FASTRAC is a two spacecraft mission with the intent of demonstrating the capability of meter accuracy relative navigation. FASTRAC is equipped with custom differential GPS units developed at the UT-Austin capable of looking both at the encoded signal coming from the GPS satellites and the phase of the signal. This information is passed to the other satellite which then determines the relative position of the satellite. FASTRAC experienced communication issues on FAST 2 following launch, but is now fully functional following separation from FAST 1. Both satellites appear to remain fully functional and have demonstrated partial mission success with the flight demonstration of the GPS receivers. Full mission success is expected following spacecraft conjunction in the November 2011 timeframe.

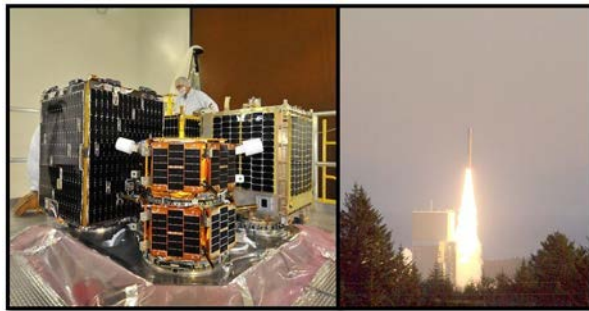


Figure 8: The figure on the left is the four microsats launched on the STP-S26 mission. FASTRAC is the two satellite stack in the foreground. The figure on the right is the launch of STP-S26 from Kodiak Alaska.

Upcoming Missions

There are a number of upcoming missions that have been selected through the competition, or have been supported for launch through other programs that will be described in this section.

CUSAT

Cornell University was the winner of the NS-4 competition with their microsatellite called CUSat (Cornell University Satellite). CUSat is manifested with STP for launch on SpaceX's Falcon 9 for NASA's Commercial Resupply (CRS) mission. CUSat has a similar mission to FASTRAC in that it is demonstrating

the capability for centimeter accurate positioning through Carrier-phase Differential GPS (CDGPS). In addition to the verification of the CDGPS algorithm CUSat intends to demonstrate closed loop relative navigation using both the CDGPS capability and on-board Pulsed-Plasma Thrusters (PPT). CUSat is in final integration and testing at AFRL and is scheduled for launch in June of 2012.

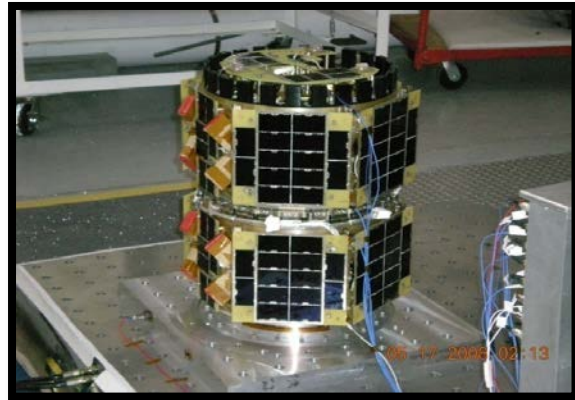


Figure 9 shows CUSat built by Cornell University. CUSat is manifested for launch in March of 2012.

DANDE

The Drag and Atmospheric Neutral Density Experiment (DANDE) shown in Figure 10, was developed by the University of Colorado-Boulder and was the winner of the NS-5 competition. Of particular interest to the AFRL Battlespace Environment Division (RVB), and Air Force Space Command, DANDE's objective is to provide measurements of atmospheric composition, drag, and neutral winds in the difficult to measure 350km-200km altitude regime. In the final phases of assembly at the University of Colorado - Boulder, DANDE is scheduled for delivery to AFRL in July, 2011. In the 2010 Department of Defense (DOD) Space Experiments Review Board (SERB), DANDE placed 34th out of 72, demonstrating the military utility and real world application of this science mission and thus AF interest. The higher ranking achieved during the SERB allows the satellite to have a higher priority to be manifested on launch opportunities. A manifest for DANDE is currently being worked with the Space Test Program.



Figure 10 shows the Drag and Atmospheric Neutral Density Experiment Satellite built by the University of Colorado – Boulder

OCULUS-ASR

OCULUS-ASR was developed by Michigan Technological University and is the winner of the NS-6 competition. The purpose of OCULUS-ASR is to provide the Air Force Maui Optical Station (AMOS) with the opportunity to witness in real-time when the satellite releases the spheres as well as the deploy solar panels while they are observing it from their ground based optical sensors. OCULUS-ASR was selected in January, 2011 with an expected delivery date to AFRL in the fall of 2012. The spacecraft and mission will be briefed to the SERB for the first time this year. Due to the collaboration and selection of relevant technologies, Oculus-ASR is expected to rank well at SERB.

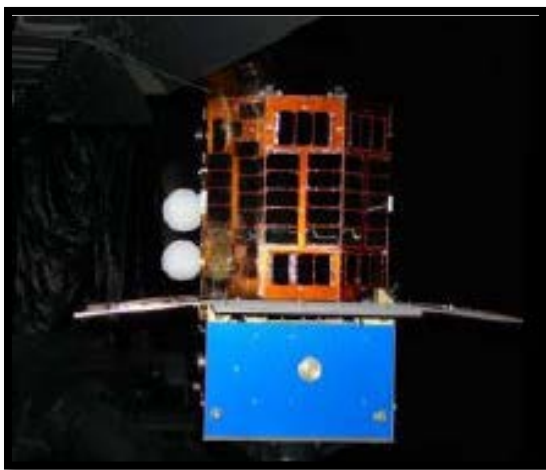


Figure 11 shows the OCULUS-ASR satellite built by Michigan Technological University.

Ho'oponopono

The University Nanosat Program's first CubeSat, Ho'oponopono is being built by the University of Hawaii and means "to make things right." One of the exciting developments with Ho'oponopono is that even though it was the third place finisher in the NS-6 competition, it was selected to be flown on NASA's Educational Launch of Nanosatellites (ELaNa) Initiative. Ho'oponopono is the first CubeSat to place in the top three in the University Nanosat Program and also demonstrates a strong military utility for CubeSats. The University of Hawaii is collaborating with Vandenberg Air Force Base by flying a transponder used to help calibrate C-Band radars used by the DOD, NASA, and international partners for tracking and identifying objects in space. Currently the community depends on the RADCAL satellite and DMSP-15, both operating well beyond their expected lifetime. Ho'oponopono is currently at the University of Hawaii in final development prior to system testing. Delivery to California Polytechnic Institute is in spring of 2012 with an expected launch in August, 2012 on the ELaNa 5 mission.

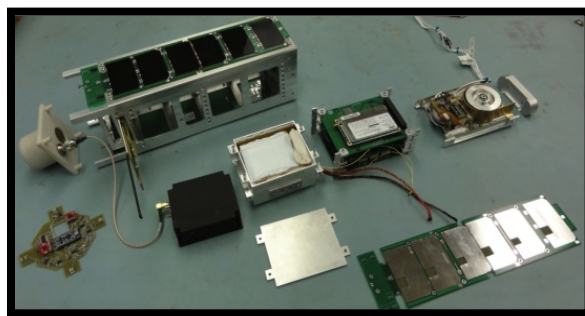


Figure 12 shows the University of Hawaii's Ho'oponopono 3U CubeSat.

Violet

Violet, built by Cornell University, was the second place finisher in the NS-6 competition and is being sponsored by AFRL's Spacecraft Technology Division (RVS) Guidance Navigation and Control (GNC) group. Violet's mission is to flight qualify a set of Control Moment Gyroscopes (CMG) as well as demonstrating various CMG topographies. Violet hosts control algorithms by Cornell as well as a number of guest investigators representing industry, government, and academia. Violet is currently at Cornell University with a scheduled delivery to AFRL in the summer of 2012. AFRL/RVS will be briefing Violet to the SERB this year. Due to the Air Force relevance we expect Violet to rank well as the DOD SERB.

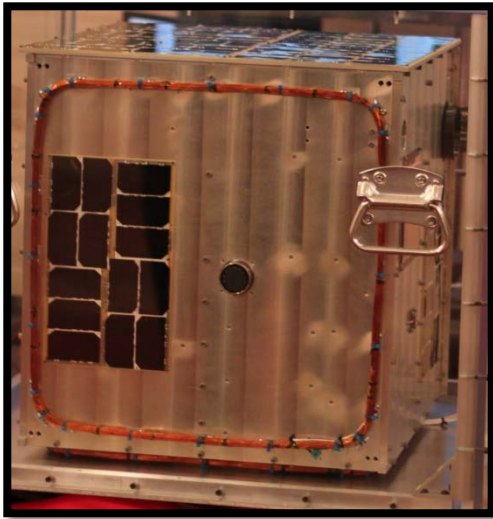


Figure 13 shows the Violet microsatellite built by the Cornell University in the NS-6 competition.

PROGAMATIC DEVELOPMENTS

A significant development in the University Nanosat Program is the growing number of CubeSats (4 of 10 in NS-7). As UNP spanned the time of the CubeSat inception and growth in capability, the quality of the original proposals submitted to the program where not sufficient enough to merit many CubeSat entries. However, with the growth in capability, and support by the community, especially the National Science Foundation (NSF), the quality of CubeSat proposals has risen. In the current competition (NS-7) there are four CubeSats out of the 10 UNP schools. Although there is general enthusiasm for this development, it raises a number of considerations. Primary among these issues is how to evaluate and select a winner when there is the (typically) greater utility of a 50kg, less complete spacecraft being compared to the (typically) more mature, but less utility CubeSat. Another issue raised by the growth of CubeSats in the program is the need to have better understanding of the educational impact of a program involving a CubeSat versus a program with a traditional 50kg spacecraft. CubeSats are naturally smaller spacecrafts with fewer number of components compared to the 50kg spacecraft. This directly impacts the number of students who get hands on development of spacecraft structures and PCBs. Both of the above concerns are being evaluated in the current competition and will be captured in a future paper.

Another focus of the program is the attempt to decrease the time from winning the FCR to delivery to AFRL. This goal is made possible by the increased support provided to the Program Office by AFRL/RVEP. In addition to the two full time members at AFRL, three additional members have joined the program in a half-time basis. This has allowed the implementation of a series of reviews to be held at the winning university that allows for a greater involvement in the post-FCR period. There has also been a number of deliverables required at each of the reviews that have been added with the intent of helping the students step through the design process. However, the effectiveness of these added programmatic elements can only be evaluated first at the NS-7 FCR, and subsequently in future reviews.

A third emphasis of the program is the attempt to have more satellites fly from the program. As was discussed earlier the more satellites that fly the better the educational experience is for more students. Also, the industry and government sponsors of those programs have a better chance of getting a larger return on their investment (either in time donated, money invested, or hardware given). The path forward on this goal is through potential partnerships with other low-cost, educational initiatives as well as the sponsorship of UNP satellites by other DOD programs. This effort has already begun to be affective through the sponsorship of Cornell's Violet nanosatellite by AFRL/RVS, and the Hawaii's Ho'oponopono by NASA's ELaNa initiative.

The final initiative is to leverage the large University Nanosat Program small satellite development effort in the cooperative ground station effort. UNP represents schools from Hawaii to Boston with all of the university programs developing ground stations. In the past only schools that win the FCR have developed their ground stations to the point it was operationally able to talk to satellites. In a cooperative ground station effort schools in the current competition would be able to develop a ground station able to support the current flying UNP satellites. With one UNP satellite already flying, two manifested for launch in 2012, and potentially three more in the next two years this could be a valuable resource to the community. Currently the Program Office is investigating various cooperative ground station efforts such as the GENSO network. In addition to GENSO, UNP personnel have been in discussions with DOD, NASA, and academia concerning other ground station efforts. Currently there are four UNP schools working on being compatible with the GENSO network. FASTRAC, the NS-3 winner and currently flying, is compatible with GENSO and has been having beacon data sent back to UT-Austin by

the UNM center COSMIAC located in Albuquerque, NM. Although it is not the intent of the Program Office to mandate a ground station solution, the idea would be to help facilitate a solution for those schools who would be interested in participating.

EDUCATIONAL DESIGN CYCLE

One of the challenges of programs that participate in the educational satellite arena (this includes government programs as well as academic programs) is to have a metric to clearly evaluate the impact of the program. Naturally the biggest impediment to student developed satellites is the time from program start to launch. Typically the launch for a microsat or CubeSat may be years beyond when the satellite was built due to the availability of launches, the challenge of integrating secondary spacecrafts onto a launch vehicle, or primary spacecrafts not wanting to manage the risk of a secondary spacecraft. With the new institution of launch programs such as the NSF CubeSat program, NASA's ELeNa mission, and STPs continued commitment to including small satellites hopefully this will reduce the launch lead time. However, the current climate still is not conducive to students building satellites merely for the educational experience. If the average student is able to work two years on a satellite program the inception of a program to on-orbit operations could be three student cycles. With each student cycle the information that student knew needs to be transferred to the next student. When a new student is involved in work that a previous student has done the tendency is to redesign the system, or gravitate to something he or she can take ownership of. This creates a programmatic hurdle that can derail many teams.

In addition to the student turnover constraint the cost of launch for these educational spacecrafts by the US space industry is substantial, even for a CubeSat. Merely launching these satellites for the sake of education is arguably a poor use of research and educational dollars. Many of the lessons learned in systems engineering design can be learned through an affective high altitude balloon program, a sounding rocket program, or possibly a combination of them. Both of these programs have the greatly added benefit of allowing the students who built the hardware to see how it behaved on the balloon or on the rocket, greatly increasing the educational experience.

Each educational satellite program must weigh its program against the utility of these terrestrial based, highly successful programs. For a student satellite effort to be worth the investment by universities, industry, and the government it arguably must have three components to it: a rigorous engineering program, the ability to

provide continuity between student cycles, and an engaged user for the satellites data. If any of the three components are missing, or ineffective, the entire program's utility is greatly reduced.

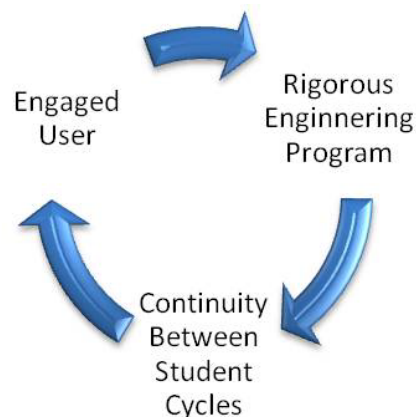


Figure 14 illustrates the need for all three components in an educational satellite program

A Rigorous Engineering Program

In spacecraft design even the smallest of problems can render a satellite's mission virtually useless. A best effort, a design rational often used in academic circles, is not acceptable when it comes to spacecraft design due to the cost of the entire program (satellite build, testing, and launch), and the engineering hours spent on the program. It is not possible for most subsystems on a satellite to work, but have a few be almost working. Either the satellite works to minimum success criteria, or it is not worth flying. The impact of not having a subsystem work on a balloon launch or rocket launch, is significantly less than a satellite. Therefore a rigorous engineering program is essential to any program. This rigorous program must be able to understand the requirements driving the design, understand the science or technology of the primary mission, and understand every spacecraft subsystem needed to ensure mission success.

Continuity Between Student Cycles

If a program is to be truly educational and successful there must be a way to have continuity between student cycles. The turnover rate with students on programs is approximately two years. Oftentimes this can be extended by students continuing on for a graduate degree at the same school and staying involved in the program. Although this is not that uncommon it is not the norm. This requires for a program to have an effective means of transferring the intellectual heritage from one student on to the next. This oftentimes is most

effectively done by the PI or research associate who is heavily involved in the program as well as a programmatic structure that mixes new students with departing students.

Engaged User

An engaged user is essential for an affective student built satellite. Even if a satellite is launched and meets its mission objective, if the information is not used by the community then the launch was not worth it. A program must ensure that the user of the satellite data is actively involved in the design process, and is willing to be around to use the data once the satellite is launched. The satellite customer needs to be involved throughout the process mostly as a supplier of high level requirements. Oftentimes academic programs will guess at the needs of customers and will spend a considerable amount of effort on a design aspect that the user ends up not caring about.

CONCLUSION

The University Nanosat Program is a partnership between the Air Force, AIAA, and US universities to develop the US aerospace workforce. In addition, the program works towards creating innovative technologies while supporting university spacecraft hardware development laboratories. It meets the three requirements discussed in the previous section for an affective educational satellite program, although it is working on creating a better partnership between the end user and the students. Over the years the program has influenced the academic careers of thousands of undergraduate and graduate students, as well as many more thousands of high school and elementary students. It is recently celebrating the success of the launch and operations of FASTRAC while looking forward to the significant number of upcoming launches. The program is working on increasing the military relevance of the satellites with its university programs as this is a key requirement for a higher ranking on the DoD Space Experiments Review Board.

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